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Motor Control in Keyboard Tasks and Research on Morse Code Copy

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A review of biomechanical and motor behavior characteristics of rapid finger responses and current issues in motor behavior is related to development of the skill of receiving Morse code. Previous research on Morse code provides the background for three experiments described in this report that investigated the organization of component processes in the Morse code copy task, with particular attention to the motor response. Experiment 1 examined the effects of variables related to component processes of the Morse code copy task. Experiment 2 studied the motor response component of the copy task. Experiment 3 analyzed cognitive organization and response preparation for a motor task using Morse code stimuli. The principal findings were that the pattern of elements constituting a Morse code signal was the only significant variable influencing response time; vocal reaction time to Morse code was longer than keyboard entry of the character; subjects separated into groups based on their ability to perform the speeded Morse copy task; and successful subjects demonstrated evidence of superior response organization and preparation. The results help clarify the process of skill acquisition in the Morse code copy

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task and suggest implications for predicting successful performers and for improving training methods.

FOREWORD

The MANPRINT, Manpower and Personnel Research, and Training Systems Research Divisions of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) have jointly established a task force to provide support to the U.S. Army Intelligence School at Fort Devens, MA (USAISD) in efforts to reduce attrition in 05H (Morse Intercept Operator) training. This task force was established and continues to function under a memorandum of understanding (MOU) among USAISD, ARI, and the National Security Agency.

Under this MOU, the impact of organizational, selection, and training variables on the Army's mission to train Morse Intercept Operators for all services is being examined. This report describes one of the studies conducted within the training area. Specifically, it focuses on the activity of the component processes central to the task of encrypted Morse code reception.

The research reported here was conducted under the Scientific Services Program administered by the U.S. Army Research Office. It has been briefed to the Directorate of Evaluation and Standardization, U.S. Army Intelligence School, Fort Devens, MA.

MOTOR CONTROL IN KEYBOARD TASKS AND RESEARCH ON MORSE CODE COPY

EXECUTIVE SUMMARY

Requirement:

The interception of encrypted communications transmitted in Morse code is a critical intelligence-gathering task. The Army has the primary responsibility of training operators to perform this task for all four services. Although the training of these operators is effective, high attrition and the length of time to completion make it inefficient. The processes underlying the development of motor skill during learning the Morse code copy task are not well understood, but they are central to the performance. This report describes three experiments designed to improve our understanding of the motor components underlying performance of the Morse code copy task.

Procedure:

Experiment 1 measured choice reaction time to auditory stimuli in four conditions: keyboard response and vocal response to Morse code signals and keyboard and vocal response to tones of different frequencies associated with letters of the alphabet. Stimulus characters were chosen to represent variables related to the copy task. Experiment 2 examined choice reaction time with a keyboard response to groups of Morse code signals with a speeded presentation. In Experiment 3, Morse code stimuli (1 to 5 items in a group) were presented in advance, and keyboard reaction time to a response signal was measured.

Findings:

The principal findings of these studies were that the pattern of elements constituting a Morse code signal was the only significant variable influencing response time; vocal reaction time to Morse code was longer than keyboard entry of the character; subjects separated into groups based on their ability to perform the speeded Morse copy task; and successful subjects demonstrated evidence of superior response organization and preparation.

Utilization of Findings:

These findings have direct implications for training techniques in developing skill on the Morse code copy task. They can be used by training developers when making decisions on the need for increased practice on difficult characters, the utility of the "voice-finger drill" during the character learning phase, the ability to predict later performance from early performance, and the procedures of stimulus presentation during character learning.

MOTOR CONTROL IN KEYBOARD TASKS AND RESEARCH ON MORSE CODE COPY

CONTENTS

Page

LIST OF FIGURES

CONTENTS (Continued)

MOTOR CONTROL IN KEYBOARD TASKS AND RESEARCH ON MORSE CODE COPY

INTRODUCTION

Morse code copy is a complex task that involves keyboard entry of random alphanumeric stimuli. It is unique because of the added translation process from receiving the auditory code to response determination and because of the absence of linguistic information.

A review of research findings in typewriting and rapid finger responses from biomechanical and motor behavior perspectives will be presented in order to identify fundamental characteristics of motor control relevant to Morse code copy. Current issues in motor behavior will be discussed in relation to research on Morse code copy. Finally, three experiments investigating component processes of the Morse code copy task, with special attention to characteristics of the motor component, will be presented and discussed in relation to the current issues in motor behavior. Recommendations for training and suggestions for future research directions will be outlined.

TYPEWRITING AND RAPID FINGER RESPONSES

Typewriting using the Sholes (qwerty) system is the most common keyboard task. Because it is a form of motor behavior that requires extensive periods of training, it is well-suited to testing psychological theories of complex motor skill and its acquisition. It involves a form of response output that can be suitably quantified, engaging both cognitive and motor components.

Studies of motor control involving rapid finger responses on just one key, or a limited number of keys, have attempted to reduce the complexity of keyboard entry in order to isolate specific components of the performance. This type of investigation enables the cognitive underpinnings of the motor task to become evident.

Biomechanics

The field of study concerned with the mechanics and physics of motion in biological systems is known as biomechanics. It employs kinematic methods to measure and describe movement (e.g., oral structure, finger, limb, whole body) in terms of displacement, velocity, and acceleration as a function of time.

In biomechanical investigations of motor control, structural movements of the fingers are studied with strain gauge displacement transduction as well as electromagnetic, photoelectric, ultrasonic, and X-ray microbeam techniques for more precise measurement than was formerly thought to be possible. Using these techniques, investigators in biomechanics have pursued three principal lines of research in gathering data about motor control: (1) observations of movements; (2) studies in which unanticipated perturbations have been applied to movements; and (3) effects of loads on continuous movement.

Gentner, Grudin, and Conway (1980) used high-speed films (100 frames per second) to record an expert typist transcribing sentences on a computer keyboard at approximately 90 words per minute (WPM). The

time at which a finger started a continuous movement toward a key was measured for each keystroke. When comparing identical sentences, the starting times of the typist's finger movements were found to be highly variable even though the inter-keystroke reaction time demonstrated regularity of the keystrokes. These findings were confirmed by Gentner (1981) in high speed filming of a typist producing repeated sentences, where irregularity of initiation time and even of element order contrasted with the regularity of the key presses.

These data suggest that the controlled output of the motor system is not a parallel series of independent movements, each directed to a consistent target in three-dimensional space. Instead, it seems to be evident that only the combination of potentially independent movements is being controlled. This kind of covariable interdigital trade-off has been taken to reflect the phenomenon of motor equivalence (e.g., Hebb, 1949; Lashley, 1930), described as the ability of a motor system to achieve functionally the same end result with considerable variation in component movements involving different muscles and joints.

Not only do these studies underscore the importance of the concept of motor equivalence to an understanding of motor control in the sense of producing different movements which achieve the same result, but they also point out another crucial aspect of motor behavior, namely, uniqueness of movement (Sheridan, 1984) --movements are never exactly repeated even when duplicating a response. For example, in the simple task of repetitive tapping of the finger there is considerable variability of interresponse intervals (Van Galen & Wing, 1984).

Biomechanical measurements indicate that repeated attempts to achieve a desired performance result in movement variations at this level of analysis with differential feedback as a consequence. Schmidt (1982) has termed this the novelty problem--we produce movements that we have never made before--thus, repetition and consolidation do not contribute to learning a skill as much as do invention and progression (Whiting, 1980). For example, learning to play golf does not involve remembering and repeating an exact swing from a previous game but adapting the information already learned to improve the swing in the current situation.

Related to this idea is the problem of context-conditioned variability (Bernstein, 1947/1967). With an objective to produce a certain motor outcome, activating any given muscle or muscle group results in a movement that differs with the context. The variability is *context-conditioned in* that *context* influences the variable relationship between muscle excitation and movement.

Bernstein (1947/1967) identified the three major sources of context-conditioned variability as stemming from anatomical, mechanical, and physiological factors. Anatomical sources of variability arise in those joints (e.g., shoulder, hip) where the role of agonist and antagonist are not fixed to particular muscles but change with the trajectory of the movement and the context in which it occurs. The role that a muscle plays is conditioned by the context of

the movement. Mechanical variability is reflected in the lack of a given innervational state of a muscle to result in a fixed movement consequence. The relationship between the state of a muscle and the movement that results (consequence) varies according to the context. Physiological variability reinforces the view that a fixed relationship cannot be assumed between muscle states and movements. Because of the nature of the nervous system, instructions from the cortex to the muscles are not transmitted without modification. Inputs from the spinal cord act on a motoneuron; hence, the state of the spinal cord, interactively with the message from the cortex, determines what actually occurs in the motoneuron (Turvey, Fitch, & Tuller, 1982).

Despite the apparent uniqueness of each movement, an obvious feature of skilled performance is the consistency and stability of temporal and spatial structure (Hancock and Newell, 1985; Sheridan, 1984). Terzuolo and Viviani (1979; Viviani and Terzuolo, 1980) required their subjects to type words in different contexts and measured the time intervals between successive keystrokes. It was found that for each word, there is a characteristic sequence of time intervals between keystrokes, which remains invariant over changes in the absolute time taken to type the word. When a load was introduced by weights attached to the fingers, the temporal pattern of keystroke ratios was not affected although the total duration often increased.

Another feature of motor behavior has emerged from studies in which either a load or an unanticipated perturbation has been applied to ongoing movements. Not only is skilled action stable and *consistent*, but it is also capable of adjustment based on changes in available information (modifiability of movement) (Sheridan, 1984).

In a task where subjects produced cyclical movements of the index finger while simultaneously uttering a repetitive syllable, Kelso, Tuller, and Harris (1983) applied a sudden unexpected perturbation in the form of a torque load to the finger, forcing it off its trajectory. An examination of the movement waveform revealed the finger to be back on track in the cycle immediately following the perturbation. It is interesting to note that a change in the speech waveform also occurred, but the result was increased amplification of the syllable in the cycle following the perturbation.

A study by Wing (1977) of repetitive finger tapping measured compensatory attempts in timing of the movement when auditory feedback was perturbed. Subjects made series of repetitive index finger taps on a touch plate which after a constant brief delay were followed by a short auditory tone. Once in each sequence the auditory feedback was perturbed--increased 20 ms or 50 ms or decreased 10 ms--perturbations small enough to be undetectable by the subjects. The effect of this type of perturbation was shown to carry over to the second interval after the response with the perturbed auditory feedback but the mean intertap interval returned to normal by the third interval following perturbation.

As mentioned above, Terzuolo and Viviani (1979; Viviani & Terzuolo, 1980) found only keystroke duration to be affected by adding weights to the fingers of typists. The ratios of keystrokes plotted over time remained invariant, contributing further data in support of subjects' ability to modify movement in the face of a load applied to the movement structures.

A summary of the observations made from a biomechanical standpoint reveals the following features of motor performance presented thus far:

1. motor equivalence--the motor system can reach the same result in different ways;
2. uniqueness of movement--movements are never repeated exactly;
3. stability and consistency of movement--temporal and spatial structure of movement does not change with variation in other characteristics;
4. modifiability of movement--movements can be adjusted to changes in the environment.

Motor Behavior

As well as lending support to observations discussed thus far, behavioral studies yield data relating to an additional feature of motor performance, namely, seriation of control elements. Henry and Rogers (1960) reported that initiation time for a finger key release was faster than initiation time for a movement to grasp an object suspended in front of the body which, in turn, was faster than for a movement to several targets. They argued that an increase in complexity created an increased amount of time required for coordination and direction of the neural impulses into eventual motoneurons and muscles. To account for these results, they formulated the memory drum theory of neuromotor reaction which proposes that a well-learned movement response is executed under the unconscious control of a previously stored motor program, analogous to the operations of a computer. When a program is needed, it is selected and sent to the appropriate neuromotor coordination centers where it is translated into efferent commands to the muscles to initiate the movement response. According to Henry (1980), "to program means to place in 'permanent' motor-memory storage (by extensive practice of a task, for example) a neuromotor plan called a program" (p. 163). The stored motor program is accessed to control post-stimulus programming, which involves organizing neuromotor details and channeling neural impulses to the motor nerves to start the movement. The memory drum theory has been refined for over 25 years and their original concept of the motor program has been extended to typewriting tasks (Sternberg, Monsell, Knoll, & Wright, 1978).

Sternberg et al. (1978; Sternberg, Wright, Knoll, & Monsell, 1980) carried out experimentation on sequences of rapid finger movements in typewriting, using the same simple reaction time (RT) procedure as they had formerly employed in speech experiments. On each trial a list of one to five letters was displayed for 1 s, followed by a fixed delay of 2.4 s for rehearsal, and then two brief noise bursts as the countdown

signals. On 80% of the trials an auditory "go" signal occurred at the end of the delay, indicating to the subject to type the letter list. Twenty percent of the stimulus presentations were catch trials, on which the reaction signal was omitted, for the purpose of preventing anticipations. Professional typists performed in two conditions--one-hand sequences of letters and alternating-hands sequences of letters. Results showed that RT increased with sequence length, albeit in a different way for the two conditions. The RT function was significantly linear for lists of one to five letters in the alternating-hands condition. The mean RT function was significantly nonlinear in the one-hand condition for lists of one to five letters, however, a linear function emerged when the plots were formed only for lists with more than two letters. For both conditions, duration functions were best described by fitted quadratic equations, in agreement with their speech data, and the production rate (time between strokes) functions approximated linearity. Effects of the number of strokes and the type of stroke transition (one-hand or alternating-hands) on mean production rate were additive. As in their speech data, the sizes of the latency and production rate effects were very similar, but only for the alternating-hands condition. Additional typewriting experiments were carried out using single words, continuous word strings, discrete nonwords, repeated keystrokes, and letter strings with embedded doublets. Not all of the data led to the results which have been outlined above, but Sternberg et al. preferred to treat these as anomalies which they did not seek to explain. Taken as a whole, however, the research of Sternberg and his colleagues defines another set of observations for which a theory of motor programming must provide an account--the sequencing or serial order of response elements.

Klapp and his colleagues (Klapp, Wyatt & Lingo, 1974) also studied finger movements as well as speech. The responses they investigated were a long button press and a short button press, corresponding to the Morse code _dah_ and _dit_, respectively. They reported that choice RT was longer to a _dah_ than to a _dit_, and attributed this effect to the additional time it took to program the lengthening component of the _dah_. Simple RT yielded a shorter mean latency than choice RT but no differential RT effects for _dit_ and _dah_, even though subjects were encouraged to prepare the response in advance in order to shorten RT. Under less stringent conditions, when subjects were not instructed to plan the response in advance, both choice RT and simple RT demonstrated longer latencies for _dah_ than for _dit_ although, in terms of mean latency, simple RT was not significantly shorter than choice RT. They concluded that the effects of programming the serial order of individual items can be measured with simple RT only if subjects are not taking advantage of the opportunity to program the response prior to the "go" signal. Again, the assumption is made here that "programming" takes place during the RT interval, whereas programming may indeed take place ahead of time with the RT latency period measuring retrieval of an already constructed motor program. In addition, instructions to minimize RT may actually encourage subjects to prepare ahead of time only an initial segment of a response, with the remainder to be organized as the performance unfolds.

A number of other investigators have used behavioral techniques in the study of finger movements in typewriting or finger tapping experiments (see Cooper, 1983, for a review). Studies relevant to the motor programming issue in terms of preparation time phenomena have been carried out by Shaffer (1978, 1981, 1982) and Rosenbaum (1985).

Shaffer developed a theory of motor programming of skilled performance in which an abstract structural representation in the program specifies both an ordered sequence of response elements and expressive features of the sequence, such as rhythm, stress, and intonation. He proposed a general conception of motor programming that would account for musical performance as well as speech and typing, requiring the translation of an abstract intention of action through a succession of representations (a "hierarchy of abstractions," 1982, p. 110) of the intended action leading to output, achieved by calling procedures or rewrite rules from memory. Skilled performance thus consists of the continual alternation of at least a structural and a command representation of output in the motor program. Temporal coordination is achieved through an abstract timekeeper or clock, and skilled movement aims at targets in space and time. Timing is therefore based on an internal schedule of the targets of movement instead of movement onsets. As Shaffer's main concern is with the timing of skilled motor acts in terms of sequence organization and execution time, so Rosenbaum is attuned to these problems.

Based on their studies of finger tapping responses, Rosenbaum, Kenny and Derr (1983) proposed a tree-traversal model that predicted the latency and production rate results of Sternberg et al. (1978), as well as serial position effects for which Sternberg's model could not account. Rosenbaum, Inhoff, and Gordon (1984) expanded this idea to also account for those special conditions in which RT decreases with the length of the sequence, They proposed a model of choice RT performance that assumes a hierarchically organized motor program is first "edited" to resolve any response uncertainties. Editing up to the point of the first uncertainty takes place before the RT signal and continues from that point to the end of the program after the signal is recognized. An execution pass then allows responses to be produced when their elements are encountered in the motor program. Most recently, Rosenbaum, Hindorff, and Munro (1987) refined the hierarchical editor model to allow execution to begin before editing is completed. They assume that subjects minimize response time by employing a scheduling strategy for execution, and accomplish this by reducing the means and variances of interresponse times. Although this model also accounts for the serial position anomaly in the data of Sternberg et al. (1978), it introduces its own problems, the most obvious being that editing is useful only up to a restricted sequence length, for response choices that share the same representation, and not beyond. If the sequences are too long or too different editing will not be useful.

A representative body of literature on motor control has been reviewed in order to expose manifestations of skilled performance that investigators have discovered in the biomechanical and behavioral

analyses of movement. The following characteristics of skilled performance have been observed in typewriting/finger tapping tasks:

1. motor equivalence
2. uniqueness of movement
3. stability and consistency of movement
4. modifiability of movement
5. serial order of control elements

The next section will outline some of the main issues in the area of motor behavior that are specifically applicable to Morse code copy.

MOTOR BEHAVIOR ISSUES

Controlled and Automatic Processing

Controlled processing has been described as serial, conscious, rule-like processing that occurs in novel or inconsistent information processing tasks (e.g., Schneider, 1985). It is slow, effortful, and capacity-limited. Automatic processing is parallel, associative retrieval processing that occurs in well-practiced consistent tasks. It is fast and fairly effortless. Practice smooths the performance of motor and cognitive tasks and reduces the number of resources needed to be allocated to process information (Best, 1989). Although there are pronounced individual differences in the effect of practice (Neisser, 1963), these effects are relatively small for highly speeded simple decision tasks with familiar content. In such tasks, improvements have been found to be primarily attributable to motor response processes (Pellegrino, 1988).

Pellegrino (1988) has studied the development of automaticity in skill acquisition and has concluded that some components of a task may achieve automaticity while others do not. The deciding factor seems to be consistent stimulus-response mapping within and across tasks. He also found that his measure of information processing efficiency was related to a standard reference measure of perceptual-spatial ability. Measures of general cognitive ability were predictive of performance in the early stages of learning a skill, and were also related to subsequent performance differences among subjects, but did not provide any indication of an individual's rate of change in performance on a variety of information processing tasks. This is consistent with the view that "aptitude scores may not be the best indices of an individual's trainability or capacity to become more efficient in performing certain tasks and in executing certain processes in a highly efficient and automated mode" (Pellegrino, 1988, p. 137).

Woltz (1988) also found that general cognitive abilities predicted performance differences that occurred early in skill acquisition but he did not find much predictive relation to performance differences that existed after practice. On the other hand, the role of abilities that were specific to a task, such as motor skills in motor tasks and perceptual skills in perceptual tasks, increased with practice. He presented evidence that a release from the processing limits associated with controlled attention to a task facilitates the development of

automaticity in performance. He concluded that controlled attention processes were related to declarative and proceduralization aspects of skill learning and that automatic activation processes were related to the later composition and strengthening of initial sequential productions.

Ackerman (1987), in his study of individual differences in skill learning, found evidence for a shift from controlled to automatic processing after consistent practice. He also suggested that general cognitive abilities predict early performance, which relies on controlled attention processing, and that perceptual and motor aptitudes predict later, highly practiced automatic performance. Woltz (1988) modifies this claim by stating that the capacity for automatic activation may be a general aptitude that puts limits on procedural learning and on developing automaticity in cognitive skills. This capacity is related to active long-term memory nodes, assumed to be relatively independent of the short-term memory capacity related to controlled processing.

Logan (1988) presents a different idea in describing his instance theory of automatization. He offers it as an alternative to the modal view, making the argument that beginning performance is limited by a lack of knowledge or memories of the task rather than by resource limitations. The learning mechanism he describes is the accumulation of separate episodic memory traces that occur with practice and that produce a gradual transition from performance that is based on computing a solution from a general algorithm to performance that is based on "single-step, direct-access retrieval of past solutions from memory" (p.493). This theory assumes that a task is performed <u>differently</u> when it is automatic than when it is not and that what changes with practice is the data base on which the memory operates. In other words, learners make a discrete shift to a different strategy, to using memories instead of an algorithm. Consequently, instance theory predicts a reduction in concurrent task interference with the development of automatization because automatization gives subjects more ways to perform a task.

<u>Errors</u>

Errors in transcription typing are thought to be an important source of insight into the cognitive and motor organization underlying keyboard performance. Both descriptive and functional classifications have been proposed. Grudin (1983) studied error patterns in novice and skilled typists and concluded that a keystroke is represented according to the hand, finger, and finger position that specifies it so that a common error is assigning one of these three components incorrectly. Deactivation of representations is also needed to avoid perseverations. Multicharacter response units were found to be represented during execution because certain errors occur within such units and others occur across units. Based on the differential pattern of errors compared to the experts, he speculated that novices may not form these multicharacter units.

Salthouse (1984) interpreted results from his studies of errors in transcription typing as evidence against multicharacter preparation or "chunking." For example, his typists detected a large proportion of their errors immediately and not at the end of multicharacter groups. This finding is supported by research on the "stopping span," in which subjects are instructed to stop typing when they hear a tone. Logan (1982) found that typists stopped after an average of one to two letters (200 - 500 ms) regardless of the length of the word. Grudin and LaRochelle (1982) concur that the two-character response unit is the largest that is frequently employed.

Temporal Overlap

Additional evidence against the chunking hypothesis comes from a comparison of the typing of normal texts and sequences of random letters (Salthouse, 1984). Typing speed was greatly impaired if the normal text was presented one letter at a time, indicating that preview of a series of letters is important in achieving skilled typing. This finding had originally led Book (1908) and Coover (1923) to postulate the chunking hypothesis, in which typists developing their skill move from a mode of analyzing character by character to one involving larger units such as words and phrases. Salthouse also found, however, that typing speed was greatly impaired when the random letters were presented one at a time, indicating that preview provided a similar advantage with meaningless material as with normal text. Therefore, the preview advantage cannot be due to simply chunking of meaningful patterns (e.g., of words and phrases). Salthouse's explanation is a competing hypothesis that skilled typists make their processing operations overlap. This overlapping in the performance of many of the operations involved in making keystrokes is impossible when the material to be typed is displayed only one or a few characters at a time. The indication is that a cognitive component is present in skilled typing. Intensive practice results in the elimination of unnecessary operations, in the ability to execute more than one operation at a time, and in a reduction in the attention demanded of the typist by certain operations. He suggests these characteristics as goals towards which training should be oriented.

LaRochelle (1983) has also found evidence for temporal overlap among the stages of processing involved in discontinuous typing using isolated words or word-size letter strings. He argues that orthographic effects are factors that influence higher levels of processing involved in the preparation of the typing response and not the motor level.

According to Gentner (1985), in addition to an increase in speed differentiating between the typing of novice and expert typists there is a shift in the underlying determinants of the execution. The performance of student typists is limited primarily by cognitive constraints, whereas the performance of the expert typists is limited primarily by motor constraints. Thus, during acquisition of typing skill, there is a general shift from cognitive to motor limits on performance. Expert typing is characterized by parallel mental

processes that overlap in time, overlapped hand and finger movements, a decreased load on conscious cognitive resources, and reduced variability of the interstroke intervals (Gentner, 1985).

<u>Linguistic Context</u>

Shulansky and Herrmann (1977) tested both touch typists and non-touch typists in copying sentences that varied in grammaticality and meaningfulness. The touch typists showed no difference in their overall rate of typing for the various types of sentence strings, whereas the non-touch typists exhibited a substantial reduction in rate with successive degradations in linguistic form. These results suggest that touch typists can prepare their output without consideration of syntactic or semantic constraints. In fact, they are often unaware of the content of what they are typing and can type prose and random word texts with similar speed and accuracy. However, performance for highly skilled typists does deteriorate when the copy consists of zero-order random letter texts, in which all letters are equiprobable in their appearance (Shaffer & Hardwick, 1968). Thus, the typist utilizes linguistic context to some degree when processing sequential keystrokes.

The possibility of visual-to-phonological recoding was suggested by Cooper, Ehrlich, Paccia, Weiss, & Damon (1981) but only for the fastest typists they tested. Coming subsequent to visual perception and prior to storage of information in a short-term buffer, this step is questionable.

Rumelhart and Norman (1981) found in their studies of skilled typing that the time it takes to strike particular keys depends upon the context in which the letters occur. Not only is linguistic context important, but they also stress that every model of skilled typing must incorporate the *entire environment* within which the typist operates, from the input of the information, to the cognitive and motor control systems, to the shapes and mechanical characteristics of the hands, fingers, and keyboard.

MORSE CODE

Bryan and Harter (1897, 1899) were pioneers in research on complex motor skills. They studied the sending and receiving of Morse code, and found that learning curves for receiving, and not sending, had plateaus in which periods of gain were followed by periods of no gain (the plateau), and then periods of gain again. These results have not been replicable and the validity of plateaus has become uncertain. For example, Tulloss (cited in Taylor, 1943) found little difference between receiving sentences, unrelated words, nonsense material, and random letters, unexpected from an hypothesis of plateaus, which would predict variation in receiving these types of materials.

Bryan and Harter (1897) also found that the rate of receiving varied greatly. Among novices, the ability to send was greater than the ability to receive, but with experts the reverse was true.

Learners seemed to enjoy sending Morse code but treated practice in receiving as "painful and fatiguing drudgery" (p.50). They found that years of daily practice in receiving at the usual rates would not bring an operator to his own maximum potential because when forced to a higher rate in order to qualify for a different position he could easily do so. In fact, men who were operators for many years often never improved beyond a receiving baseline. An additional finding was that cryptic code could not be received as rapidly or accurately as natural words.

Further studies of Morse code were carried out by Keller (1943; Keller & Taubman, 1943), comparing methods of teaching code reception as well as analyzing errors in receiving code. Using the code-voice technique of training (presentation of Morse code signal, pause for transcribing, voiced identification of the signal by an instructor), he found the only difficulty to be in the stage of transition to a five-word-per-minute level of reception in which the signals are presented closer together and are not identified until the end of a sequence. His remedy was fourfold: (1) reduce the three-second interval for responding to two seconds until a new proficiency level is reached; (2) raise the criterion for mastery at the three-second response interval in order to decrease RT further and induce over-learning; (3) send signals in pairs at a rate of five-words-per-minute for each but with a three-second response interval; and (4) use occasional no-voice trials at the level of three-to four-words-per-minute.

A more recent study has attempted to find factors that would predict success in Morse code training (Wyant & Creel, 1982). It was found that, in general, student failure could be attributed to a combination of adaptational, motivational, and task-oriented aptitude variables, although these results may have reflected the training process because some of the materials were administered after instruction had begun. Predicting success prior to training was less reliable.

RESEARCH ON MORSE CODE COPY

The primary issues that appear to impact upon the Morse code copy task can be identified as:

1. development of automaticity
2. identification of task components
3. classification of errors
4. measurement of motor skill
5. analysis of cognitive underpinnings of response organization.

It is advisable to proceed with investigations along these lines, with a two-fold focus: (1) examining the differences between successful and unsuccessful Morse code receivers; and (2) comparing alternative training strategies on task components. The goal is to facilitate skill acquisition, improve training efficiency, and predict future performance.

As mentioned earlier, individual differences in process execution and the development of automaticity have been found to correlate with individual differences in global and specific aptitudes (e.g., perceptual-spatial ability) and not IQ. Automaticity in a task may be facilitated by eliminating unnecessary operations, increasing ability to execute more than one operation at a time, and reducing attention demanded of certain operations. Process efficiency is related to practice. Practice should be carried out on the components of a task, otherwise the performer may get to criteria but not to the level of automaticity or to the level of combining a set of procedural representations in the form of productions. Thus, the goal of training should be to make processing operations overlap, and in order to do this, training must occur on component processes (Boff& Lincoln, 1988).

Components of the Morse code copy task need to be identified. This can be done initially by cognitive task analysis, to be followed by empirical verification. Then, training should be developed to rapidly build the component skills. Next, component practice should be combined in extended training in order to optimize speeded skilled performance (Schneider, 1989).

Errors will occur in auditory perception, character recognition, and response production. Classification of these errors will provide information on component processes and task performance.

One component of motor response processes, which are the basis for improvements in performance beyond a certain level (Pellegrino, 1988), is motor skill. Measurements of fine motor coordination, perceptual-spatial aptitude, and touch-typing from dictation (auditory input) may be found to correlate with the amount of time necessary to develop automaticity in motor response processes. This may lead to the generation of predictor variables which would allow judicious selection of candidates for training.

The cognitive underpinnings of response organization may be related to the development of automaticity. For example, with increased skill the performer may plan larger units of the response, or planning and programming may overlap. In addition to preparing a response ahead of time, execution-time processing may be carried out simultaneously. Individual differences in formulating and carrying out action plans and motor programs may correlate with success in the motor response required in the speed-building phase of Morse code copy.

Three experiments will be reported which begin to address the issues of identification of the component processes of the Morse code copy task, and analysis of response organization and execution by examining the differences between successful and unsuccessful Morse code receivers. The first experiment employs choice RT in an investigation of the component processes of the Morse code copy task and the variables that influence response time. The second experiment examines the motor component of the Morse code copy task when the presentation rate is speeded. The third experiment explores the cognitive organization and preparation of the motor response to the

speeded Morse code presentation. Successful and unsuccessful subjects are identified in each experiment and a comparison of their performance is discussed.

EXPERIMENT 1

The purpose of this experiment was two-fold: (1) To investigate the component processes of the Morse code copy task; and (2) To determine the variables influencing response time to Morse code signals. The voice-finger drill (subvocalizing the associated character before transcribing it), is a common practice employed in Morse code copy training situations and therefore is an integral component of the copy task. Since auditory-vocal RT is generally longer than auditory-digital RT (Izdebski & Shipp, 1978), it was predicted that making a voice response to a Morse code signal would take longer than making a keyboard response, arguing against the voice-finger drill as an efficient teaching method. Eliminating this component would also simplify the copy task.

Decoding the Morse signal is a component process that is not present when responding to a simple tone, therefore, measuring RT in both types of tasks would indicate the response differential. It was predicted that choice RT in response to a Morse code signal would take longer than choice RT to a simple tone, with the difference indicating the processing time required to decode the Morse signal. A similar differential should be found between voice RT to Morse code signals and voice RT to simple tones.

Variables postulated to have an effect on choice RT were: duration of the Morse code signal, number of elements in the signal, the pattern of elements in the signal, typing the character with the left versus the right hand, typing the character with a specific finger, and the position of the character on the keyboard. It was predicted that response time to stimulus characters could be differentiated on the basis of these variables. With this information, training could be modified to accommodate aspects of these variables that contributed to task difficulty.

A choice RT task was employed with four conditions. In the first condition subjects learned to associate letters of the alphabet (only four letters were used for each subject) with tones of high, medium high, medium low, or low frequency. When a tone was presented they typed the corresponding letter. In the second condition, when the tone was presented they pronounced the corresponding letter aloud. In the third condition subjects learned to associate letters of the alphabet with their corresponding Morse code signal. When the signal was presented they typed the corresponding letter. In the fourth condition, when the signal was presented they pronounced the corresponding letter aloud. Vocal reaction time and key pressing reaction time were measured in order to provide an indication of the processing time differential; it has been suggested that naming and key-pressing responses to alpha-numeric stimuli are different because they involve different processing mechanisms (Holender, 1980; Theios,

1973). In addition, the difference between reaction time to a simple auditory tone and to a Morse code signal provided information on the processing mechanisms involved in responses to these types of stimuli. Twelve stimulus characters were chosen to represent different Morse code signal durations, numbers of elements, patterns of elements, left and right hand, specific fingers, and keyboard positions--variables possibly contributing to differences in auditory perception, character recognition, and motor response time.

Method

Subjects. Twenty-four subjects, 14 male and 10 female, ranging in age from 18 to 24, volunteered in response to posted advertisements and were paid for their participation in the experiment. Every subject came for two individual sessions taking approximately one hour each. None of the subjects had any previous experience with Morse code.

Apparatus. The experiment was run on an IBM AT compatible computer using the Micro Experimental Laboratory (MEL) (Schneider, 1988, 1990) software. The display was a white P4 phosphor with a 16.67 ms decay to 1% presenting 8 x 14 dot characters measuring .5 degrees vertical at a viewing distance of 60 mm. The screen intensity was adjusted to an easy reading level and was maintained at that level throughout the experiment. An IBM AT keyboard was used for keyboard responses. Subjects typed the appropriate keys, with each key having an average delay of input to the computer of 8 ms. Auditory stimuli generated by the computer were presented binaurally through Nova 10 stereo headphones having a 50 - 15,000 Hz frequency response, and sound intensity was adjusted to an easy listening level maintained throughout the experiment. Morse code signals were presented at an 880 Hz frequency; tones were presented at 200, 532, 1000, and 3000 Hz in order to maximize discriminability. Duration of the Morse code signals was 50 ms for each dit, 150 ms for each dah, and 50 ms between each element comprising one character. Duration of each tone corresponded to the total duration of the associated character. Vocal responses were received by a low impedance, high output, unidirectional microphone held approximately 6 cm directly in front of the subject's mouth. A MEL voice key with an elementary, high gain circuit registered the vocal responses. Experimenter-controlled feedback in the vocal response conditions was given with a four-key MEL response box. The experimenter monitored the auditory signal in these conditions with stereo headphones.

Procedure. For the Morse code stimuli with keyboard entry condition and the Morse code stimuli with voice response condition four Morse code signals were played on a tape recorder and the subject learned the associated letters. When it was evident that the subject was able to respond correctly to the four letters, he/she pressed the spacebar on the keyboard in front of him/her to begin the experimental presentation. The first block of 40 trials was for practice and then four blocks of 40 trials were for data collection. After a short break there was a practice block on the second Morse code condition followed by four blocks of data collection. Reaction time and accuracy were

recorded on-line. Visual feedback for accuracy was given on the computer screen after each response in order to simulate the visual feedback given in a typical Morse code copy learning situation. At the end of every block the subject saw the average reaction time for that block, the total number of errors, and a score--the reaction time divided by 10 plus 10 points for each error. The score thus reflected both speed and accuracy, encouraging the subject to find the right balance by striving for the lowest score possible.

In the Morse code stimuli with keyboard entry condition each Morse code item the subject heard acted as the response signal and the subject's task was to type on the keyboard the correct letter corresponding to the Morse code, trying to finish typing as soon after the signal as possible. "Correct Response" or "Wrong Response" then appeared on the screen for 1 s, after which the next trial began automatically. In all conditions, the four signals were presented in random order with 1.2 s from offset of one stimulus to onset of the next.

In the Morse code stimuli with voice response condition each Morse code item the subject heard acted as the response signal and the subject's task was to say the letter out loud, trying to finish speaking as soon after the signal as possible. Visual feedback for accuracy, given on the computer screen after each response, was identical to that provided in the previous condition except that it was initiated by the experimenter. The subject's response (one of four letters) was entered on the corresponding keys on the MEL response box by the experimenter, and accuracy feedback was determined by matching the stimulus with the response, under program control. The next trial then began automatically.

For the tone stimuli with keyboard entry condition and the tone stimuli with voice response condition four auditory tones--high (3000 Hz), medium high (1000 Hz), medium low (532 Hz), and low (200 Hz)--were played on a tape recorder and the subject learned the associated letters. The duration of each tone was the same as the duration of the Morse code signal for the associated letter. Except for the stimuli, all other aspects of these two tone conditions were identical to the Morse code conditions described above.

Each subject performed in every condition with one set of four stimuli, the set assigned at random; eight subjects learned FVJL, eight learned YGKB, and eight learned RUOD. Both of the Morse code conditions were presented in one session and both of the tone conditions were presented in one session. All presentation orders were counterbalanced according to a Latin square design.

Results

Reaction time data for the individual letters for the Morse code stimuli with keyboard entry condition are presented in Figures 1 (FVJL), 2 (YGKB), and 3 (RUOD). The average reaction time was 609 ms, with a range from 347 ms for the letter Q to 736 ms for D. The Q and J

were responded to significantly faster by all subjects (Tukey's HSD was significant, $p < .001$ for pairwise comparisons of O and J with all other characters), most likely because they were the two letters with final lengthening (dah dah dah for O and di dah dah dah for J), and therefore were easily discriminable. Overall accuracy ranged from 68% for D to 99% for O with a mean of 88%, as shown in Figure 4. The particular pattern of elements that constitutes a Morse code signal was the only factor found to affect mean reaction time. None of the other variables measured--duration, finger, hand, number of elements, position of letter on keyboard--demonstrated a consistent influence. It is interesting to note that the pattern of elements, the sequence of dits and dahs, relates most closely to the component process of auditory perception of the signal. It would seem, therefore, that the perceptual process plays a predominant role in the copy task, over and above the motor process.

Average reaction time for the Morse code stimuli with voice response condition was 736 ms, approximately 127 ms slower than for the keyboard entry condition ($t(22) = 2.899$, $p < .01$). The range was from 516 ms for O to 867 ms for D. Difficulty with D in all conditions may be a reflection of the shortening effect at the end of the signal (dah di dit); the two other difficult letters L and B also have a shortening of elements at the end (di dah di dit and dah di di dit, respectively).

The overlap in range for the keyboard and voice responses to the Morse code signals indicates that both vocal and digital systems are capable of responses within the same temporal constraints for these tasks. In general, a typical reaction time for auditory-vocal responses is 195 ms and a typical reaction time for auditory-digital responses is 140 ms, with the difference of 55 ms attributed to the complex neurophysiological organization required for phonation (Izdebski & Shipp, 1978).

Figure 5 illustrates mean reaction time for the two stimulus conditions (Morse code and tone) and the two response conditions (voice and keyboard). In Figure 5a, the reaction time is presented for all stimuli; in Figure 5b, the reaction time is presented for FLBYRD, the characters associated with high and low tones. The medium high and medium low tones were more difficult to discriminate than the high and low tones, and therefore, the characters associated with these tones consistently displayed slower reaction times. Consequently, the discussion to follow refers only to the data in Figure 5b. The data in Figure 5a follow the same pattern, although the elevated reaction time for tone stimuli results in smaller stimulus and response differentials.

If we compare the keyboard conditions, we see a 325 ms average increase in reaction time for the Morse code stimuli over the tone stimuli ($t(10) = 11.76$, $p < .0001$). Because the entire Morse code signal has to be processed in order to recognize it, some of this may be due to the consistent finding of increased reaction time to stimulus-off conditions over stimulus-on conditions (Goldstone, 1968; Simon, Craft & Webster, 1971; Sticht & Foulke, 1966), that is, subjects

are generally slower to respond to the cessation of a stimulus than to its initiation. Also included is the time it takes to decode the Morse signal. Response selection, and organization and execution of the digital output take place for both types of stimuli.

Looking at the voice conditions, we see a 381 ms average increase in reaction time for the Morse code stimuli over the tone stimuli ($t(10) = 9.31$, $p < .0001$). Again, some of this may be due to the increased reaction time for stimulus-off conditions in addition to decoding the Morse signal. The extra time seen in this condition may represent auditory-to-phonological translation in addition to selecting, organizing and executing the voice response.

Comparing the tone stimuli with keyboard entry and the tone stimuli with voice response conditions, the increase in reaction time for a voice response is also evident here, although for this small sample this difference fails to reach significance ($t(10) = 1.68$, $p < .12$). On average, subjects were 68 ms slower to make a voice response to a tone than to make a keyboard response. Again, 55 ms could be attributed to the neurophysiological underpinnings of phonation. This decomposition is purely speculative; however, if we look at the data in Figure 5b, we can see that an additional 325 ms are necessary to make a keyboard response to Morse code rather than to a tone, whereas an additional 381 ms are necessary to make a voice response to Morse code rather than to a tone. So an additional 56 ms are needed for the Morse code stimulus/voice response combination. Likewise, an additional 123 ms are necessary to make a voice response to Morse code rather than a keyboard response; an additional 68 ms are needed to make a voice response to a tone rather than a keyboard response. So an additional 56 ms are needed for the Morse code stimulus/voice response condition. In other words, the difference between the Morse code differential and the tone differential is the same as the difference between the voice differential and the keyboard differential (see Figure 5). Thus, 56 ms could represent some neurophysiological processing time required for perception of the Morse code signal and for organizing voice responses.

Discussion

These results have a number of implications for the Morse code copy task. First, as stated above, the pattern of elements within a signal seems to be the major factor determining average reaction time and level of accuracy. Anecdotal evidence supports the contention that very student has certain Morse code characters that he/she also finds difficult. These findings would argue for increased practice on those characters known to be more difficult in general and those presenting particular difficulty to an individual student, because we know that reaction time latencies decrease with practice and familiarity with the stimulus. Second, simple decomposition of component processes of the Morse code copy task may be misleading. For example, we would expect the increase in reaction time for Morse code stimuli over tone stimuli to be consistent across response modalities. On the contrary, subjects were 56 ms slower to respond to Morse code stimuli over tone stimuli in the voice condition than they were in the keyboard condition. This may

be an indication in support of the contention that naming and key-pressing responses to alpha-numeric stimuli are different because they involve different processing mechanisms (Holender, 1980; Theios, 1973). Consequently, simple decomposition, without regard to the performance environment, is relatively meaningless. Third, the increased reaction time for voice responses indicates that the practice of voice-finger drill now commonly used in Morse code training classes, may actually increase the difficulty of the copy task by adding interference between the stimulus and the response. Subvocalizing the character before entering it on the keyboard not only takes additional time but it adds another complex component process to the copy task. Interference can be reduced by assigning a simple response in one modality to a stimulus (Boff, Kaufman & Thomas, 1986).

EXPERIMENT 2

The purpose of this experiment was to investigate the motor response component for keyboard entry of groups of characters in Morse code copy. In the typical Morse code training situation, students learn to copy all of the characters at a maximum presentation rate of 1.5 s between the offset of one Morse code signal and the onset of the next, with a group size of one, meaning that each character is presented and responded to individually. In the next step, they move to a group size of five at a presentation rate of 6 groups per minute (GPM). This means that five characters are presented as a group, with 1.26 s between characters and 2.94 s between groups. In this learning phase they eventually work up to receiving code at 20 GPM, with 150 ms between characters and 350 ms between groups of signals. A difficult transition for the students seems to be at 12-14 GPM, and an increase in attrition occurs at this point. In order to simulate the typical Morse code training method, this experiment presented Morse code signals at a rate of 12 GPM. Because subjects had limited practice on the individual characters in Experiment 1, the group size in this experiment was gradually increased from one to five signals. It was predicted that subjects would be able to minimize speed and maximize accuracy through the use of this incremental technique. It was also predicted that some subjects would perform this task successfully (fast speed, high accuracy) while others would have difficulty (slow speed, low accuracy), and that this separation would be related to their performance on Experiment 1.

The Morse code stimulus with keyboard entry response condition from Experiment 1 was repeated with the following change: instead of single Morse code signals the stimuli represented groups of one to five characters (letters) with a presentation rate of 12 GPM. Choice reaction time and accuracy were measured. Each subject's performance in this rapid transmission condition was compared to his/her performance in the first experiment in terms of speed and accuracy in order to examine proficiency, consistency and predictability of skill attainment.

Method

Subjects. The same 24 subjects participated in this experiment as in Experiment 1. Data were collected during two individual one-hour sessions.

Apparatus. The experimental configuration and equipment were the same as for Experiment 1.

Procedure. The basic procedure was similar to that used in Experiment 1 for the Morse code stimulus with keyboard response condition, with a few changes. Trial feedback was eliminated (again, to simulate the training situation); Feedback was only given at the end of a block. In addition, there were now 466 ms between Morse code characters (instead of 1.2 s as in Experiment 1) and 1087 ms between groups of characters, corresponding to CODEZ standards of International Morse Code for 12 GPM. The eight subjects who had learned FVJL for Experiment 1 now added RU and the eight subjects who had learned YGKB added OD. Four of the subjects who had learned RUOD now practiced FVJLRU and four practiced YGKBOD. All of the relevant Morse code signals were played on a tape recorder prior to the actual start of the experiment until the subject felt he/she knew the associated letters. When he/she was able to respond correctly to all six characters he/she pressed the spacebar on the keyboard to begin the experiment. The first block of 40 trials was practice on the new characters at the slower speed of Experiment 1. The second block was practice on all six characters at the slower speed of Experiment 1. The third and fourth blocks presented groups of two characters in the speeded condition; the fifth and sixth blocks presented groups of three characters in the speeded condition; the seventh and eighth blocks presented groups of four characters in the speeded condition; and the ninth and tenth blocks presented groups of five characters in the speeded condition. The number of characters was slowly increased in this way because subjects had great difficulty responding to each character at this rapid presentation rate. On a typical trial (in block five) the subject heard the first Morse code signal, then 466 ms later heard the second, and after another 466 ms heard the third. The task was to enter each character in turn on the keyboard, trying to finish typing as soon after the signal as possible. All characters were presented randomly.

Results

Reaction time data for individual letters are presented in Figures 6 and 7. Again, as in Experiment 1, the fastest latencies were for *O* and *J* (313 and 283 ms) (Tukey's HSD was significant for pairwise comparisons of *J* with all other characters in its group, $p < .001$, and for pairwise comparisons of *O* with all other characters in its group, $p < .001$, except *Y*), while *D*, *L* and *B* were among the slowest (507, 463, 460 ms). If we compare reaction time by group size we see that it decreases as the number of characters per group increases. This is not surprising given that, in general, latencies decrease with practice. It is interesting to note, however, that these data do not present

evidence of a speed accuracy trade-off; the characters responded to the fastest are also those that are most accurate and vice versa (Figures 8 and 9). This indicates that the subjects either knew the character well and could respond to it quickly and accurately, or they did not know the character, took time to think about it, and were often wrong. It seems that subjects were not proficient enough at the task to have their performance affected by a speed accuracy trade-off.

Comparing the performance of individual subjects on Experiment 2 with that on Experiment 1 (Figure 10), it became clear that there were some who were better at both tasks and some for whom both tasks were very difficult. For others it was mainly the speeded condition that gave them trouble. Twelve of the subjects in Experiment 1 were average performers. Five out of the six top performers on Experiment 1 were also top performers on Experiment 2. The sixth was an average performer on Experiment 2. Four out of the six bottom performers on Experiment 1 were also bottom performers on Experiment 2. The fifth and sixth became top performers in Experiment 2. Three of the remaining subjects in Experiment 2 were top performers and nine were bottom performers. What this all means is that the level of performance on Experiment 2 could be predicted by the level of performance on Experiment 1 for six out of the 24 subjects; that is, the top six subjects in Experiment 1 would be predicted to be top or average performers in Experiment 2. This type of prediction is not as clear for the bottom performers in Experiment 1 because some of them actually became top performers in Experiment 2. The average performers in Experiment 1 also split into top and bottom performers in Experiment 2.

<u>Discussion</u>

The results of this experiment have a number of further implications for the Morse code copy task. First, building up the size of the groups by adding additional characters slowly, one at a time, resulted in a decrease in reaction time. Some of this decrease is surely due to practice, but by proceeding in this way responses end up being faster for the larger groups, which is the ultimate goal of the speeded phase in learning the Morse code copy task. Going from the learning phase of single characters right into the speeded phase with a group size of five characters, as is done in the current method of training, ignores the idea of component practice, which argues for a stepwise progression in building up responses to additional characters (Boff & Lincoln, 1988). Gradually building up the rate of presentation of the groups most likely would also increase accuracy, which was very low for these subjects. Twelve groups per minute was an extremely fast rate for them to jump to from the single character presentation rate used in Experiment 1.

Second, in terms of prediction, the top performers on the single character learning phase can be assumed to carry over their skill to the speeded phase of the Morse code task. On the other hand, those who do not perform as well on the initial phase cannot necessarily be assumed to do poorly on the speeded phase (although the worst

performers in the initial phase remained the worst in this phase). Since this was a time-limited task consisting of a specific number os stimulus presentation, the indication is that the length of time subjects practice to a criterion level in the initial phase of learning the Morse code copy task may be an indication of later success for those who learn quickly and easily. For others, additional component practice may be the key to achieving success in the speeded phase. Because none of the top performers in Experiment 1 turned out to be poor performers in Experiment 2, this effort should be concentrated on the average and poor performers in order to increase their level of skill. If the goal is to increase the skill level of all students, including the top performers, then additional component practice should be provided as a regular part of the training.

EXPERIMENT 3

The purpose of this experiment was to investigate the cognitive organization and response preparation for keyboard entry in Morse code copy of groups of characters. It was also intended to compare the performance of successful and unsuccessful subjects as identified in Experiments 1 and 2. It was predicted that successful subjects would demonstrate the effects of advance preparation of an entire motor response, whereas unsuccessful subjects would not demonstrate this effect, at least for an entire response. Unsuccessful subjects would be limited by memory retrieval and concurrent processing demands.

On each trial subjects heard either a single Morse code signal or a group of two to five signals. After a brief interval of 2.5 seconds, during which they were expected to prepare or rehearse the production of the character(s), two warning tones sounded and then a visual signal to begin responding was given. The subject's task was to complete the response as soon as possible after the signal. Using this type of task, it has been shown that reaction time, measured from the onset of a signal to the onset of the first response, increases in a linear fashion with an increase in the length of the sequence to be produced (e.g., Mullins, 1988; Sternberg, Monsell, Knoll and Wright, 1978), evidence that an abstract representation of the entire response, such as a motor program appropriate for organizing and controlling response execution, exists prior to the movement. Reaction time measurements in this task should provide an indication of the cognitive underpinnings to motor organization and control in Morse code copy. With attention and perceptual factors accounted for, other influences on response organization can be investigated.

Method

Subjects. The same twenty-four subjects participated in this experiment as in the last two experiments. Data were collected in two individual hourly experimental sessions.

Apparatus. The experimental equipment was the same as that used in the last two experiments.

Procedure. Each subject was presented with the same Morse code signals he/she had learned in Experiment 2. On each trial the subject focused visual attention on a background fixation on the computer screen and then heard 1, 2, 3, 4, or 5 Morse code signals. After an interval of 2.5 s, during which the subject was expected to rehearse the production of the associated keyboard characters, two visual warning signals appeared on the screen in rapid succession, alerting the subject to be prepared for the visual "go" signal, which occurred 500 ms later. The subject's task was to complete typing the response, correctly and fluently, as soon as possible after the signal. The reaction time from the "go" signal to the onset of the response was recorded and errors were coded on-line. Visual feedback was given after every trial and at the end of every block. My principal interest was in the reaction time as a function of the length of the response, since anticipatory effects of motor programming are thought to be reflected in the reaction time interval. The first hourly session was for practice and the second session was for data collection.

Results

The results of this experiment (shown in Figure 11), averaged over 12 subjects, revealed a direct linear relationship between reaction time and number of characters for 1-4 items. There was a slight decrease in reaction time for 5 characters, therefore, linear regression accounted for only 55% of the variance among mean latencies ($r = .74$, $t(10) = 3.487$. $p < .01$). An indirect linear relationship between accuracy and number of characters was clearly evident. Linear regression accounted for 98.8% of the variance among mean accuracies, which was statistically significant ($r = -.99$, $t(10) = 28.57$, $p < .001$). The absence of a speed accuracy trade-off, at least for 1-4 characters, could be an indication of a memory constraint or competition between memory and concurrent auditory processing of incoming characters. For example, for $n = 3$, the task required the subject to attend to and process the auditory signal for the first Morse code character and commit the associated letter to memory, process the next character and remember it along with the first letter, and process the third signal and remember it along with the first and second letters. The difficulty is that the memory rehearsal must take place at the same time as the incoming signal is being processed; consequently, either the signal is missed or the previous letters are forgotten, both leading to an error in response production. This may explain why reaction time is fast and accuracy is high for one character, with a gradual decrement in both for longer strings of items.

An interesting finding appears if we examine the data from subjects who are able to perform the task successfully (fast reaction time, high accuracy) (Figure 12), separately from those who have great difficulty performing the task (slow reaction time, low accuracy) (Figure 13). The four most successful subjects clearly show a linear reaction time function ($r^2 = .91$, $r = .95$, $t(2) = 4.45$, $p < .05$) predicted by the motor programming hypothesis, that is, increased reaction time as the number of units to be produced increases (recall that reaction time measures the reaction time from the "go" signal to

the <u>start</u> of the response). The four most unsuccessful subjects demonstrate this same type of function but only for 1-4 characters and then a sharp decrease in reaction time occurs (r^2 = .06, r = .24, $\underline{t}(2)$ = .347, $\underline{p}$ >1), along with a continual decline in accuracy. This would seem to indicate that when these subjects knew the particular characters in a sequence well, they could remember them and respond rapidly (the RT only represents correct responses), but the low accuracy suggests that most of the time they were not able to respond with the correct characters. If memory were factor affecting performance on this task, it did not come into play for successful subjects for one or two characters; their reaction time and accuracy was essentially the same for these two lengths (277 and 281 ms; 97% and 96%). In contrast, reaction time already increased and accuracy decreased from one to two characters for the unsuccessful subjects (396 to 411 ms; 90% to 73%). Overall, successful subjects produced significantly faster reaction times ($\underline{t}(6)$ = 8.78, $\underline{p}$ <.0001), and were more accurate ($\underline{t}(6)$ = 4.46, $\underline{p}$ <.004) than unsuccessful subjects. The subjects who experienced success on this experiment were the most successful subjects on Experiments 1 and 2. The subjects who failed to experience success on this experiment were the least successful subjects on Experiments 1 and 2.

<u>Discussion</u>

The implications of the results of this experiment for the Morse code copy task are more specific to prediction of performance than to analysis of the task itself. At least two clearly defined groups of subjects emerged--successful and unsuccessful. Successful subjects could be identified in the first experiment as those who had good performance (fast reaction time, high accuracy) in the short period of time allotted. Unsuccessful subjects could be identified in the first experiment as those who had poor performance (slow reaction time, low accuracy). These two groups remained consistent in the next two experiments. There seems to be a continuum of performance skills for the subjects who fell between these criteria, and this group also remained consistent. This finding argues for a separation by ability after the learning phase of the Morse code copy task or for performance on this task to be used as a selection criterion for further training. Those who completed learning phase with ease in a relatively short period of time would be predicted to succeed in the speeded phase within a reasonable period of time. On the other hand, those who needed a longer time to complete the learning phase would be predicted to have more difficulty in the speeded phase, and remain in that phase for a longer time. This could lead to frustration and eventual attrition. By identifying these people early and assuming that it will take them longer in the speeded phase, one idea would be to build up speed more slowly for this group and automatically lengthen the time required in the speeded phase, thereby reducing frustration. If we consider the results from the present experiment, however, we see that the unsuccessful subjects had significantly more difficulty with this task. Because the primary skill requirement was concurrent processing (memory retention, auditory perception and character identification), it would seem to make sense to provide additional practice on this type

of skill before entering into the speed building phase. For example, at the completion of the learning phase, the transition phase could include building up the number of characters per group and the speed in gradual increments--1-5 characters at 6 GPM, then 1-5 characters at 8 GPM, and so on, possibly continuing this strategy throughout the speeded phase. Measuring the time spent learning the individual characters in the initial phase should facilitate selection of those who are potentially unsuccessful and need this type of practice, while the successful subjects could go on with the usual speeded training, thereby eliminating the need for everyone to receive increased practice.

GENERAL DISCUSSION AND RECOMMENDATIONS

Based on a review of research on motor control and on the results of these three experiments, the following recommendations are proposed:

1. Provide increased practice time on characters known to be difficult in general as well as those characters identified as difficult for a particular person.

2. Eliminate the voice-finger drill. Syllable articulation, even if silent, interferes with a manual task (see also Boff & Lincoln, 1988).

3. Measure the length of time it takes each person to pass the learning phase of Morse code training and then separate them into ability groups according to the time required to pass.

4. Send those who meet a certain criteria for time to pass the learning phase of the Morse code copy task directly on to the speeded phase; all others should receive practice on gradual building up of number of characters and speed.

5. Begin initial training in Morse code copy by repeated playing of an audio recording of each character at a speed of about 6 GPM with simultaneous identification of the character. For example, a trainee would listen through the headphones to the auditory Morse code signal for A (di dah) and see the letter presented at the same time on a computer screen in front of him/her. After a 1.2 s interval there would be another presentation of A with the associated visual letter. There would be approximately six repetitions of each character like this. At the end of learning a group of six characters, two repetitions of each of the six characters would be presented in the same way. This procedure would be repeated for learning all of the characters. Again, this should be accomplished before the actual keyboard training begins. Research on motor programming and hierarchical organization in motor control argues for less initial emphasis on actual motor activity and more on description and exposure of auditory patterns that the student will hear (see Boff & Lincoln, 1988, for a review).

DIRECTIONS FOR FUTURE RESEARCH

The most obvious need for further research is to test the recommendations outlined above. It would be useful to identify a group of successful subjects and a group of unsuccessful subjects on a task similar to that used in the first experiment and then apply a variety of these training techniques to subgroups of the unsuccessful subjects and measure the time and ability to bring their performance into line with the group of successful subjects.

The purpose of this series of experiments would be to uncover differences in the performance of successful and unsuccessful subjects

in a variety of training conditions. Additional measures and techniques could also be employed, such as incorporating extra training time on generally difficult characters and characters identified as difficult for an individual subject, and comparing a gradual increase in the group size and GPM rate with going directly to a group size of five characters at 6 GPM.

Assuming the generally accepted idea that "some people complete motor tasks faster and more accurately than others, not because they have had more practice, but because practice has suggested to them better methods of performing a task" (Boff & Lincoln, 1988, p. 1924), and in accord with Logan's (1988) view of developing automatization, the constituent decisions and movements in the learning of repetitive skills by efficient performers can be investigated and can be taught to others to speed their learning. That was, and remains, the overriding focus of this research on motor behavior in Morse code copy.

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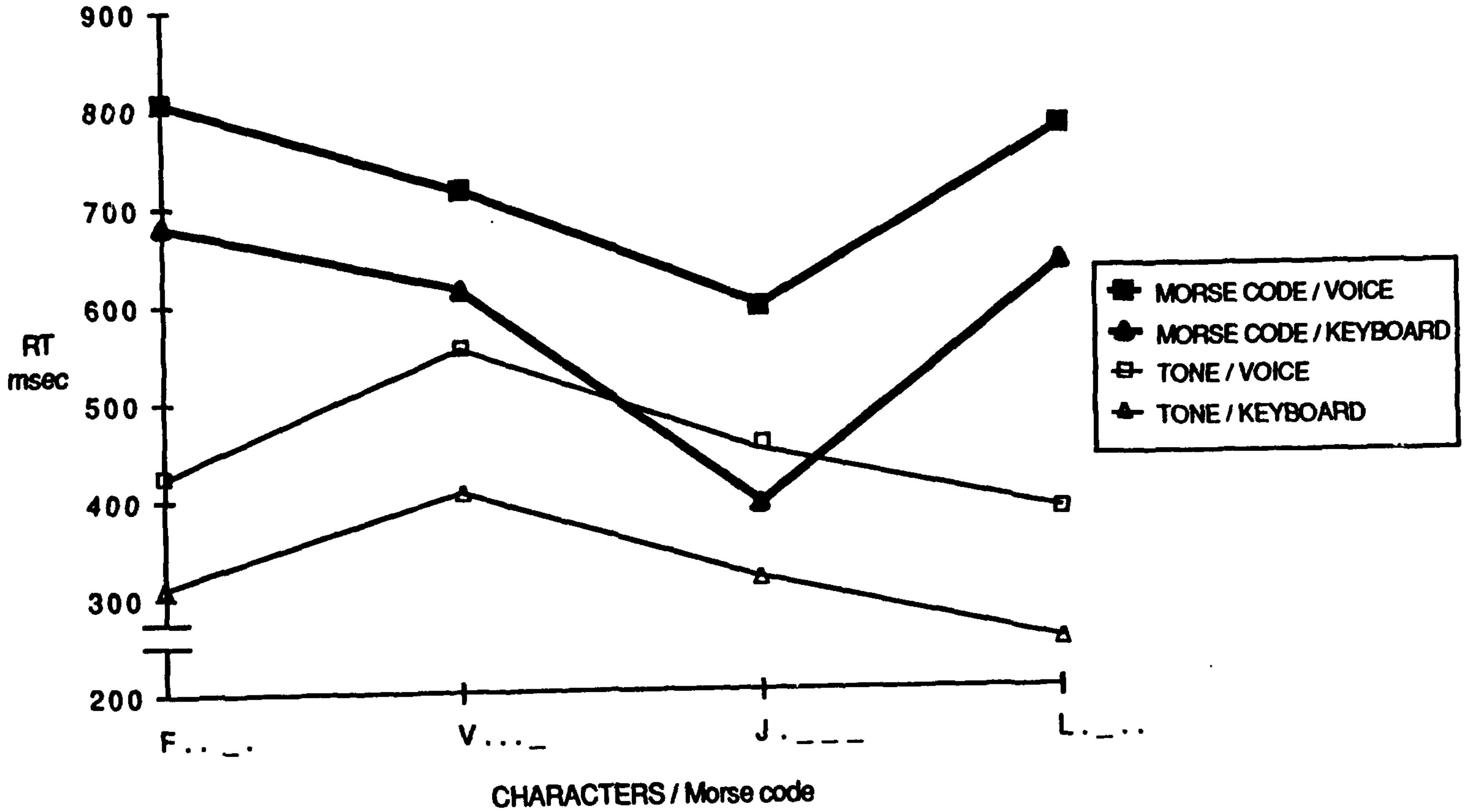

Figure 1. Reaction time to characters by response condition.

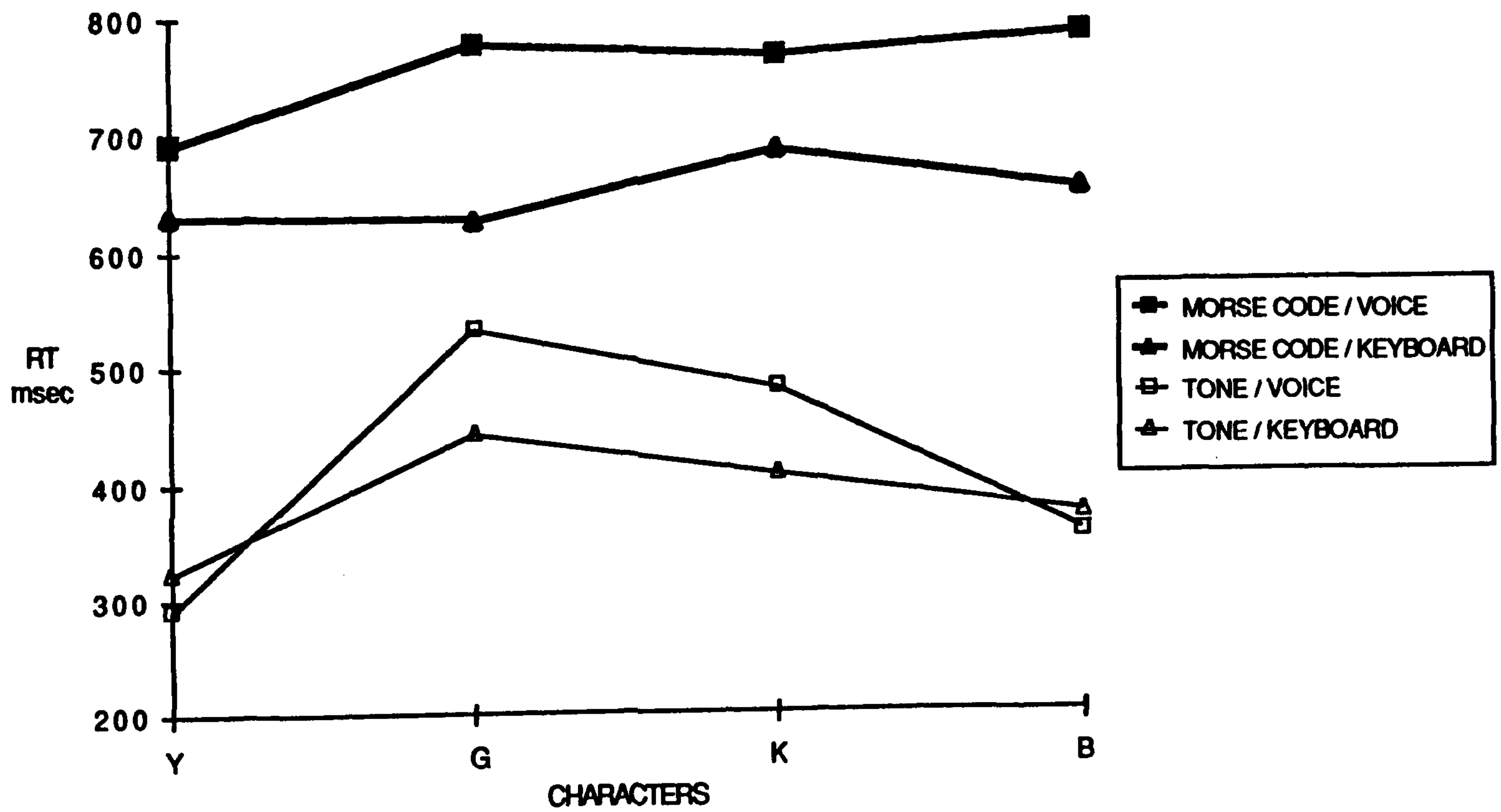

Figure 2. Reaction time to characters by response condition.

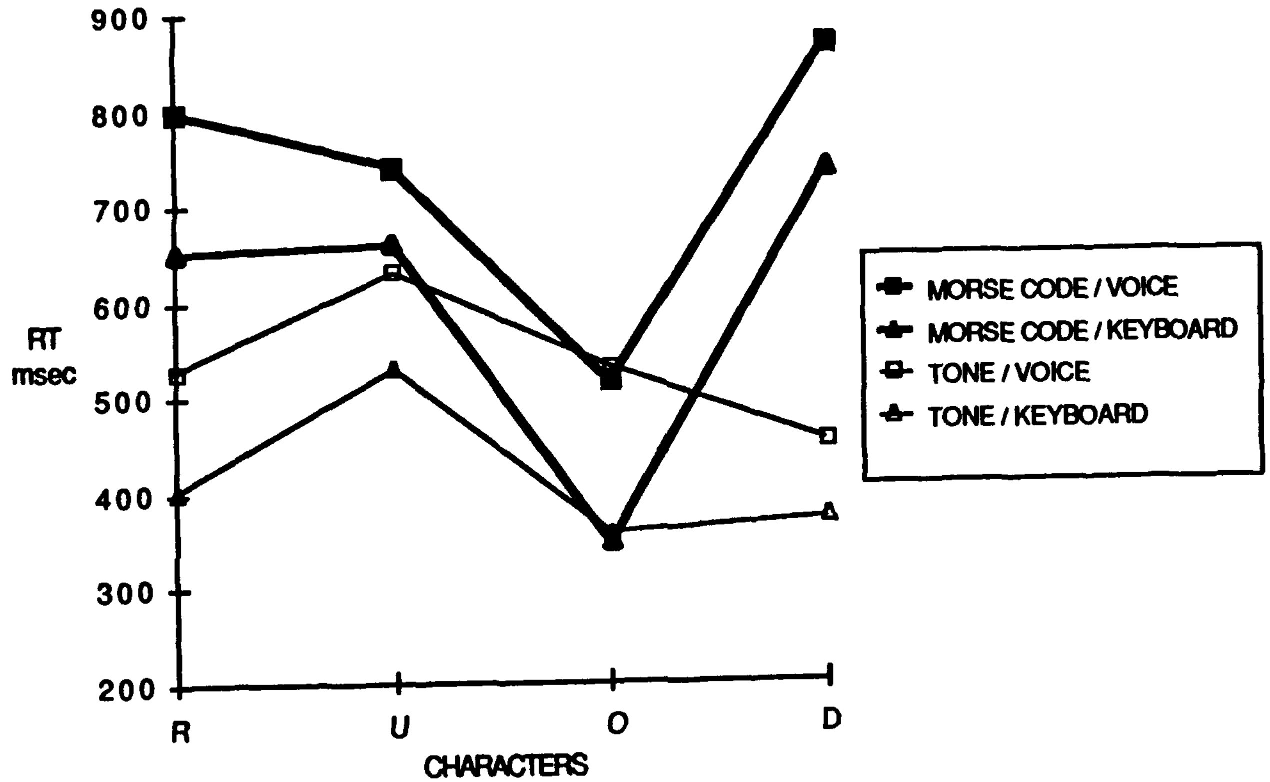

Figure 3. Reaction time to characters by response condition.

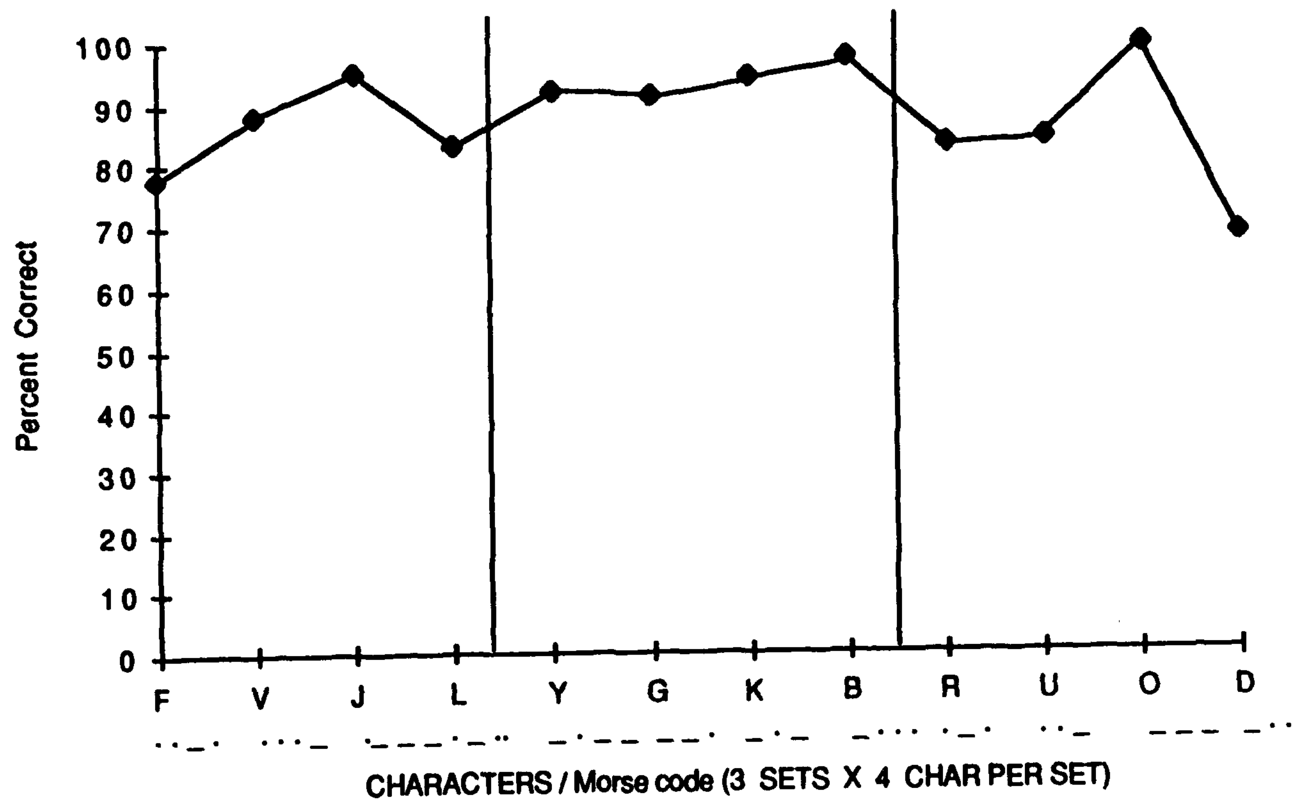

Figure 4. Keyboard accuracy for single Morse code characters.

	MORSE CODE STIMULUS	TONE STIMULUS	
VOICE RESPONSE (ms)	735.67	467.92	267.75
KEYBOARD RESPONSE (ms)	608.75	374.08	234.67
	126.92	93.84	33

Figure 5a. Mean reaction time (and differences) by stimulus and response conditions for all stimuli.

	MORSE CODE STIMULUS	TONE STIMULUS	
VOICE RESPONSE (ms)	786.83	406.00	380.83
KEYBOARD RESPONSE (ms)	663.67	338.33	325.33
	123.16	67.67	56

Figure 5b. Mean reaction time (and differences) by stimulus and response conditions for FLBYRD (high and low tones).

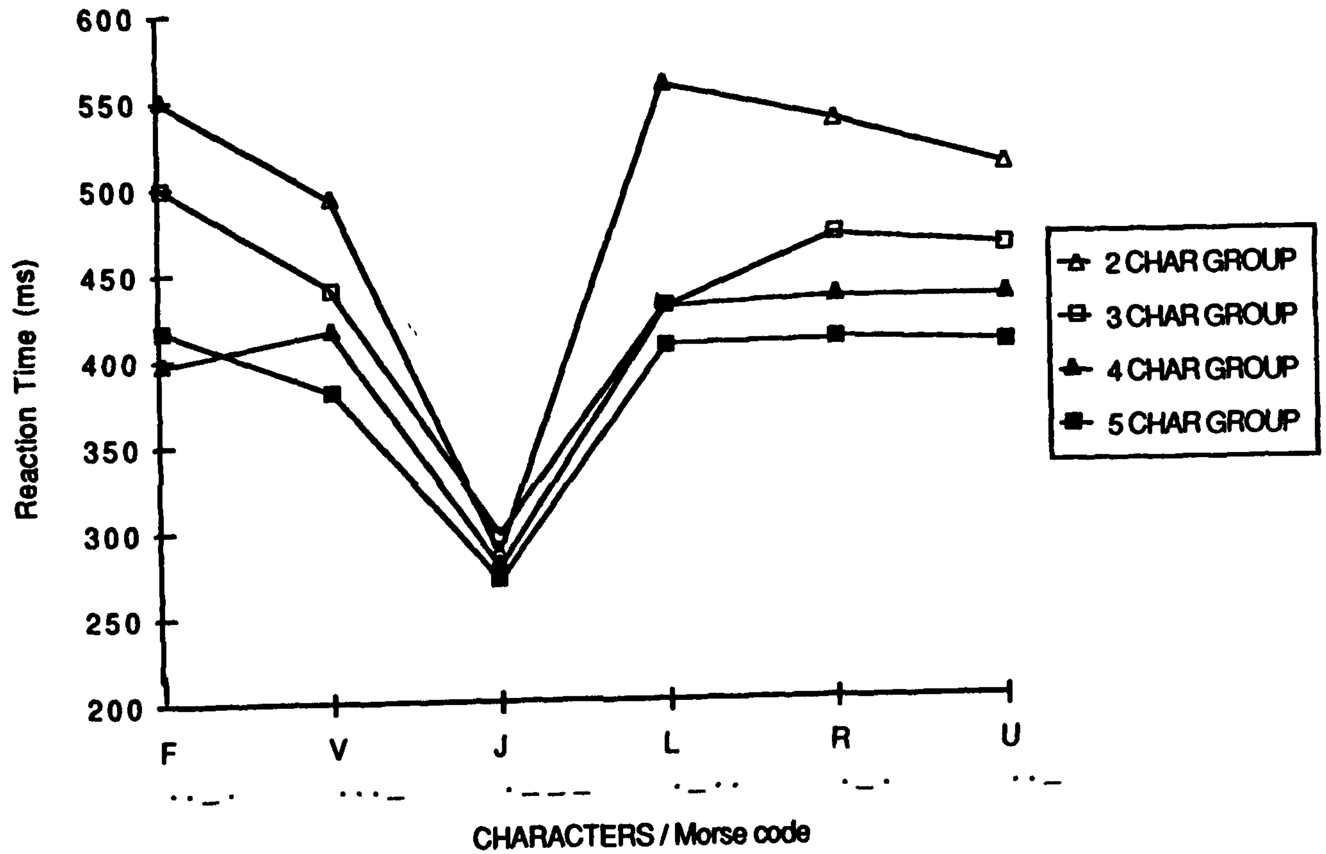

Figure 6. Reaction time, by group size, to Morse code characters presented at a rate of 12 gpm.

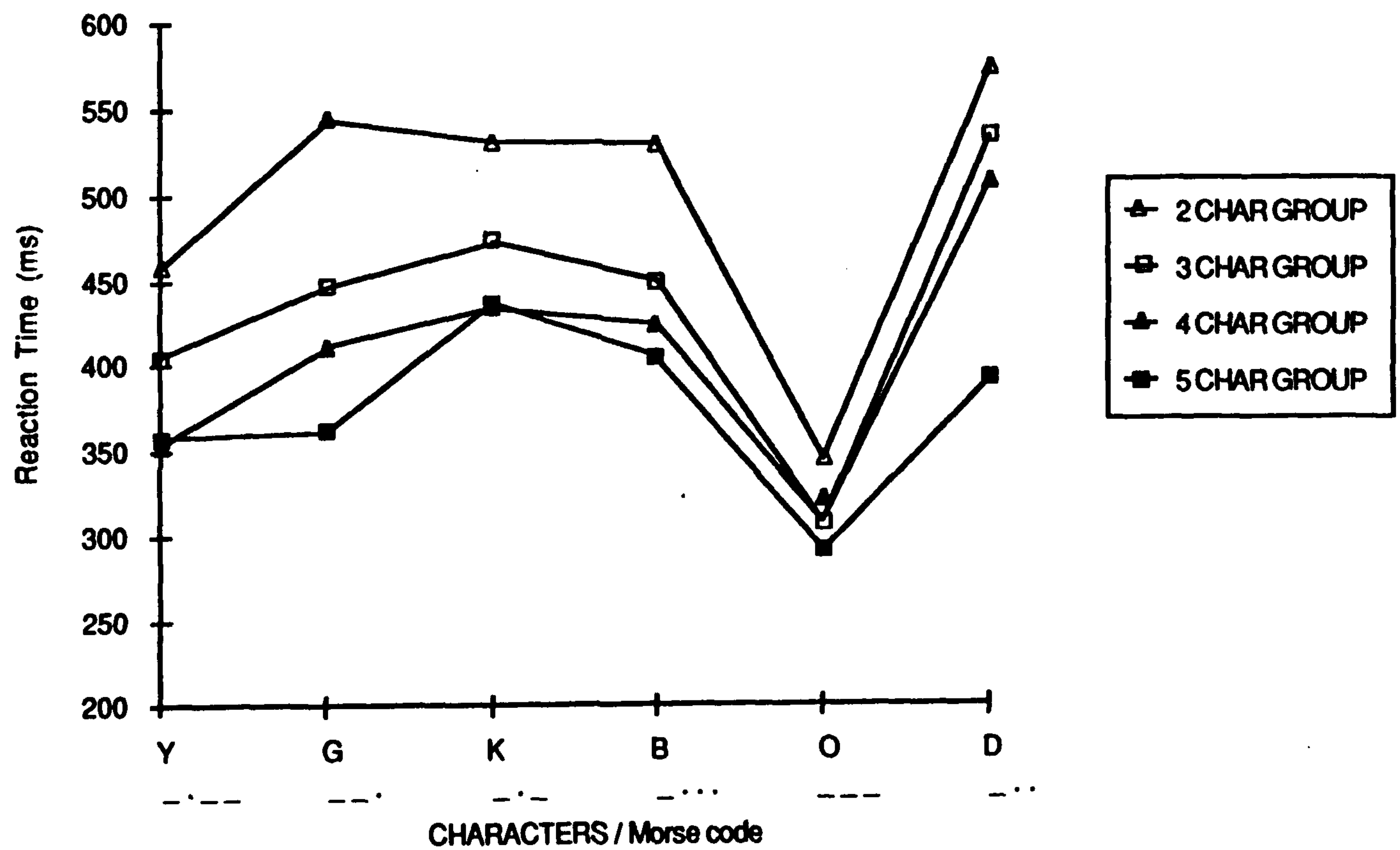

Figure 7. Reaction time, by group size, to Morse code characters presented at a rate of 12 gpm.

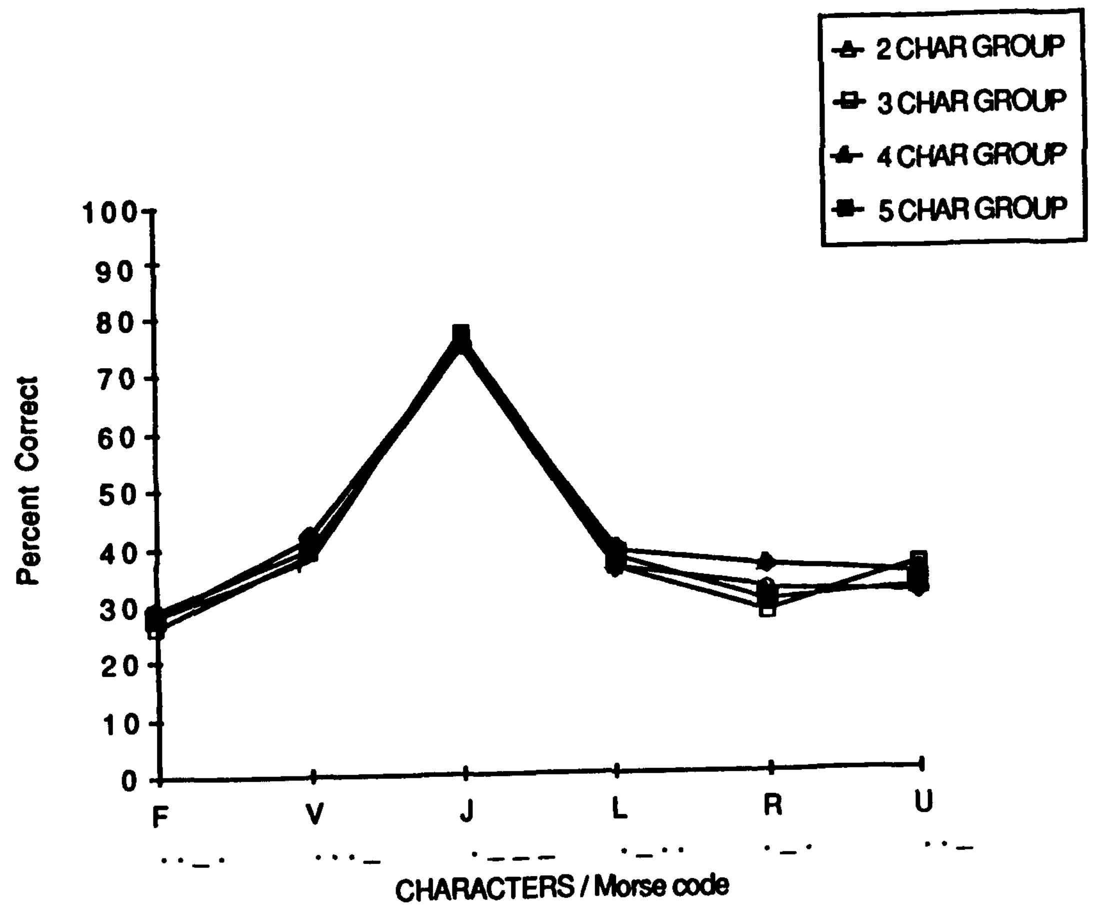

Figure 8. Keyboard copy accuracy, by group size, for Morse code characters presented at a rate of 12 gpm.

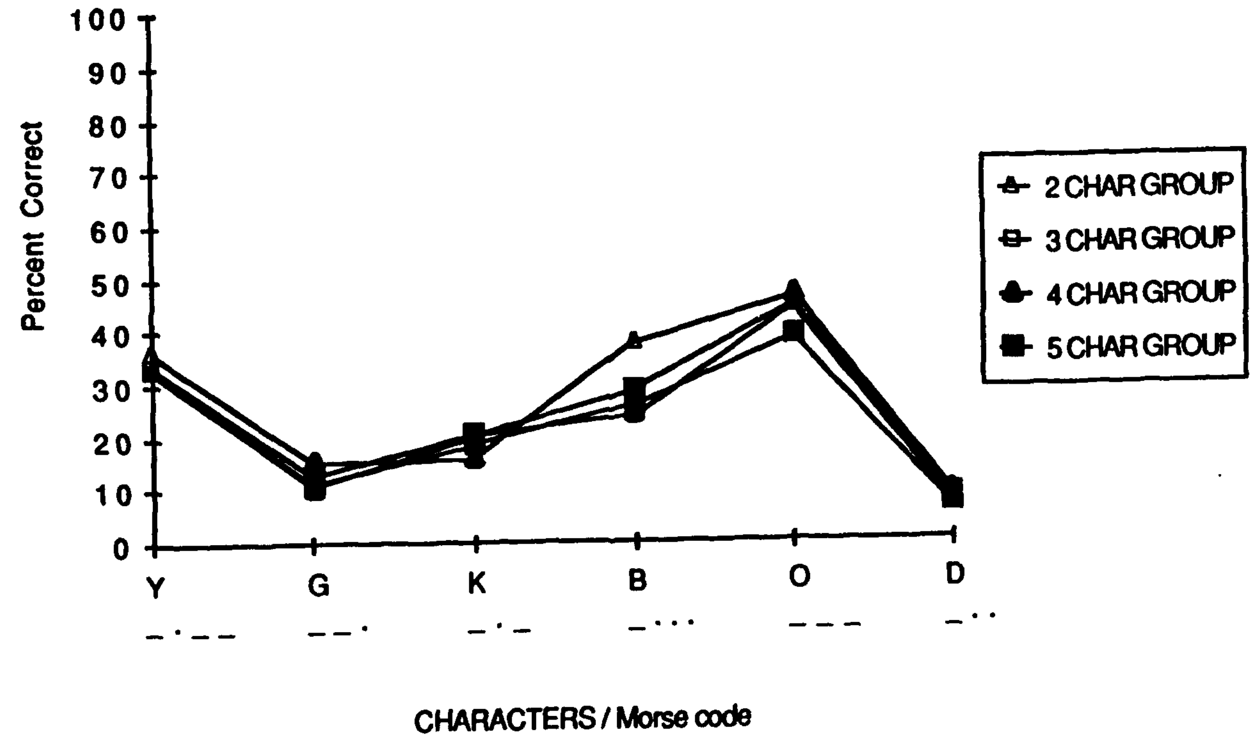

Figure 9. Keyboard copy accuracy, by group size, for Morse code characters presented at a rate of 12 gpm.

	EXPERIMENT 1	EXPERIMENT 2
TOP PERFORMANCE	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 7, 8, 9, 19, 20
AVERAGE PERFORMANCE	7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	6
BOTTOM PERFORMANCE	19, 20, 21, 22, 23, 24	10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24

Figure 10. Individual performance ranking by subject number.

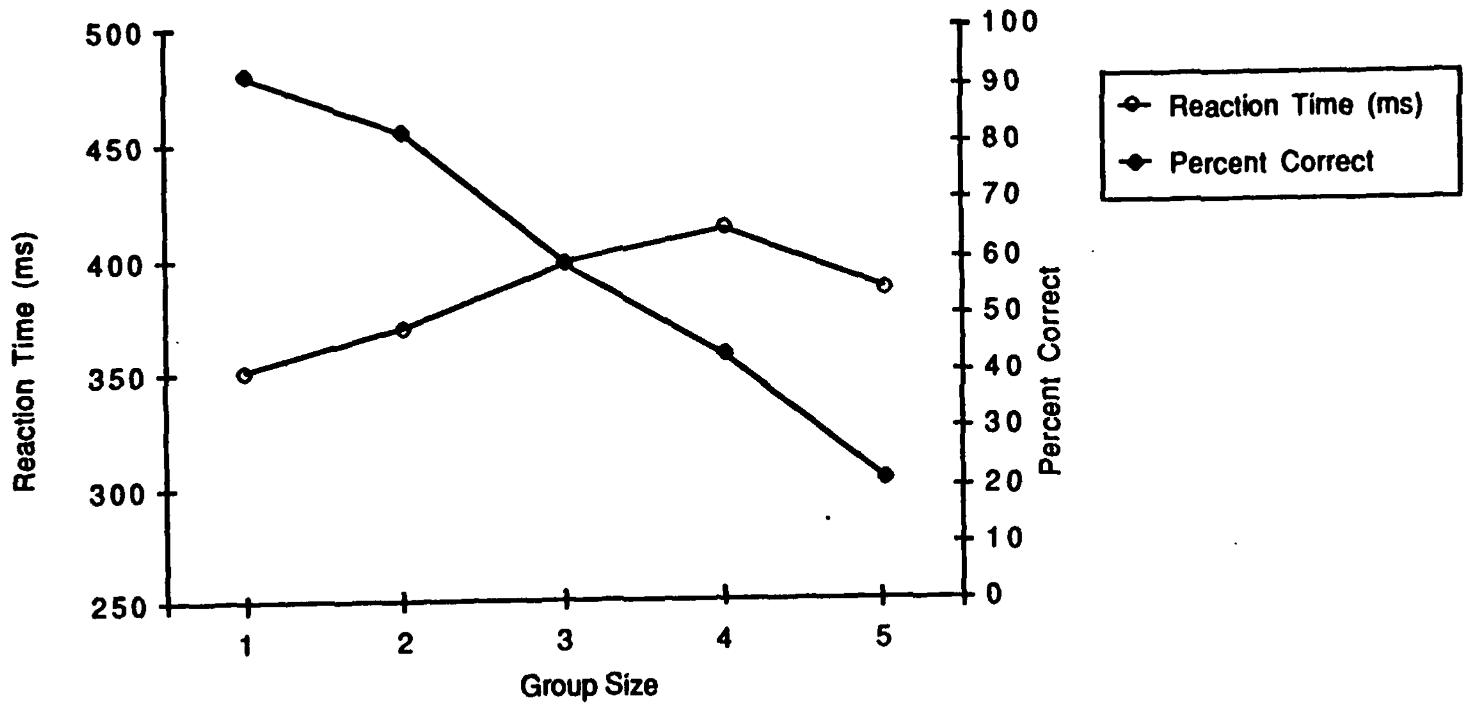

Figure 11. Accuracy and reaction time, by group size, to Morse code characters presented at a rate of 12 gpm, for all subjects.

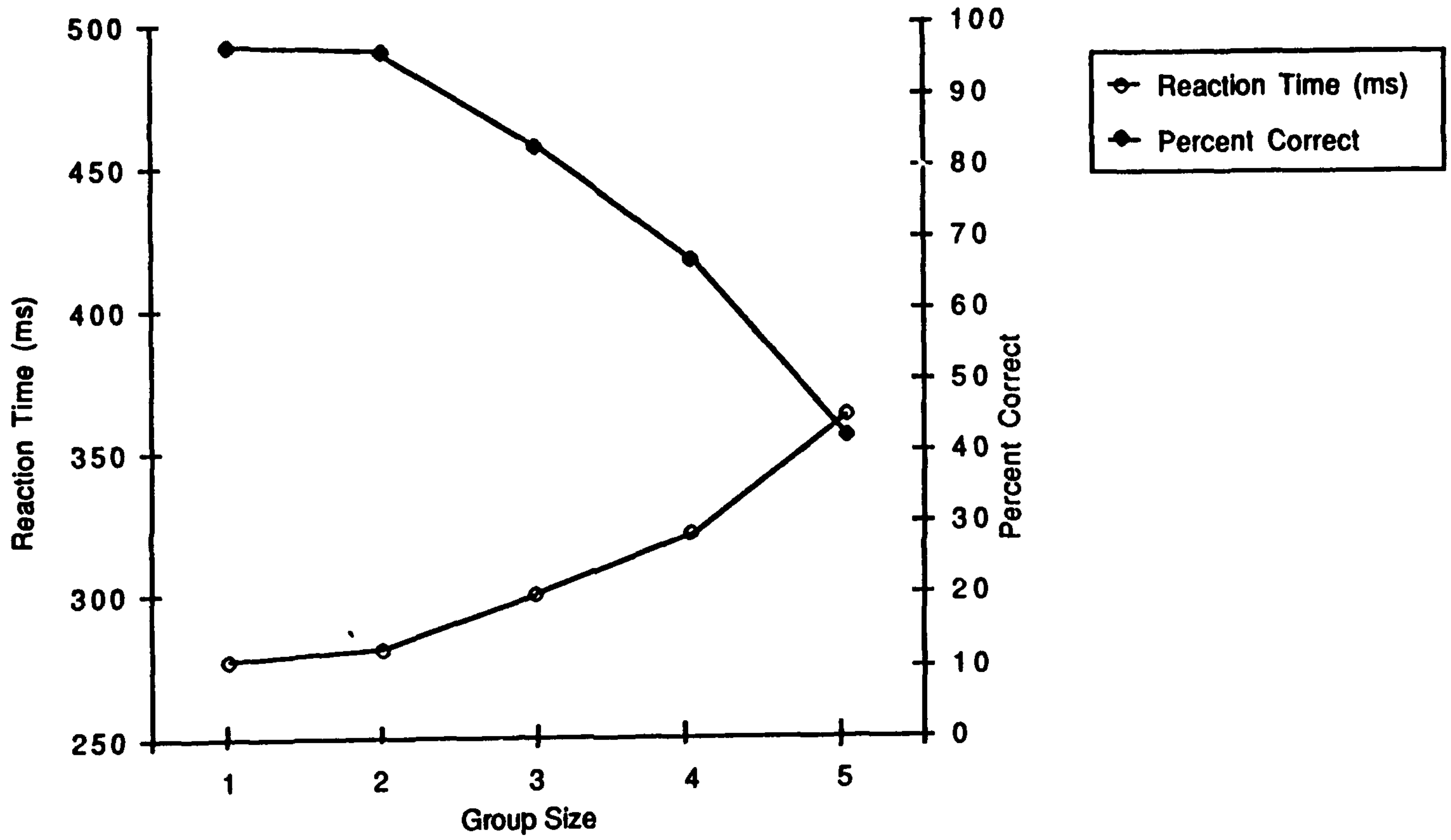

Figure 12. Accuracy and reaction time, by group size, to Morse code characters presented at a rate of 12 gpm, for successful subjects.

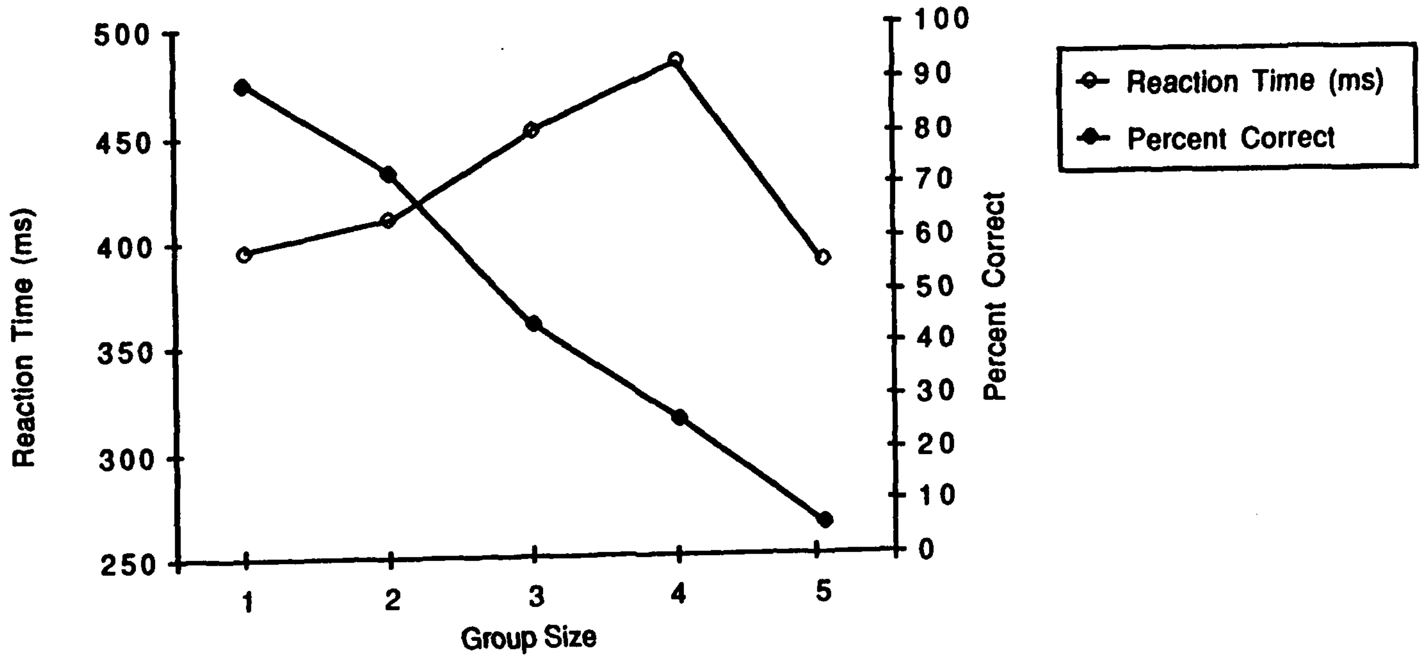

Figure 13. Accuracy and reaction time, by group size, to Morse code characters presented at a rate of 12 gpm, for unsuccessful subjects.